Overview of adaptive management for multiple biodiversity values at the Western Treatment Plant, Werribee, leading to a pilot nutrient addition study

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Abstract
Across south-eastern Australia the loss of natural wetlands since European settlement has been substantial such that even constructed waterbodies that provide a measure of habitat for waterbirds can assume importance for their conservation. Melbourne Water operates the Western Treatment Plant (WTP), occupying 10 500 ha near Werribee, primarily for the treatment of some 54% of Melbourne's industrial and domestic wastewater. During 1982 the site was included as a component of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site in recognition of its great importance for waterfowl (Anseriformes and Podicipediformes), shorebirds (Charadriiformes) and wading birds (Ciconiiformes and Gruiformes). The WTP supports other biodiversity values, with a significant population of the nationally Vulnerable Growling Grass Frog *Litoria raniformis*; a number of threatened species of plant, including the Spiny Rice-flower *Pimelea spinescens* subsp. *spinescens*; and two listed vegetation communities: *Natural Temperate Grassland of the Victorian Volcanic Plain* (Critically Endangered), and *Subtropical and Temperate Coastal Saltmarsh* (Vulnerable). This paper describes how site managers have endeavoured since 2002 to implement adaptive management to protect and promote the WTP's recognised biodiversity values during necessary sewage treatment upgrades. Results of management on waterfowl populations are obscured by the effects of the 1997–2009 drought across south-eastern Australia and species' inherent variability in distribution across this vast area. A trial addition of straw to promote waterfowl food in one wetland showed no clear benefits. However, after 12 years of close monitoring of target populations our knowledge is much improved and we believe the site retains the biodiversity values that led to it being listed as a wetland of international importance. (*The Victorian Naturalist* **131** (4) 2014, 128–146)

Keywords: waterfowl, wetlands, zooplankton, phytoplankton, zoobenthos, management

Introduction

Across south-eastern Australia the loss of natural wetlands since European settlement has been substantial, primarily through drainage or other alterations to natural hydrology. In the state of Victoria it has been estimated that between 33% and 50% of natural wetlands have been lost or degraded since European settlement (Olston and Weston 2004). This loss of natural wetlands is of considerable significance to many species of Australian waterbirds, particularly waterfowl (Anseriformes and Podicipediformes). Permanent coastal wetlands in south-eastern Australia are important non-breeding refuges for many waterfowl species during summer, when inland wetlands dry out (Frith 1982). There has been a general decline in the abundance of Australian waterbird species, particularly over the past 50 years or so, and the loss of wetland habitat essential for breeding and foraging is considered to be the main factor contributing to this (Maher 1993; Briggs *et al.* 1994, 1997; Kingsford and Thomas 1995; Kingsford 1997, 2000; Kingsford and Johnson 1998; Leslie 1995, 2001). Thus now even constructed waterbodies that provide a measure of habitat for waterbirds can assume importance for their conservation.

The Western Treatment Plant

Melbourne Water operates the Western Treatment Plant (WTP), occupying 10 500 ha near Werribee, primarily for the treatment of some 54% of Melbourne's industrial and domestic wastewater (Fig. 1). The treatment methods used at the plant have included sewage treatment lagoons, grass filtration and land filtration. Established over 100 years ago (Penrose 2001), the WTP has discharged secondary-treated effluent into Port Phillip Bay through marine outfalls for much of that time. This effluent discharge has significantly altered the

Fig. 1. The location of the Western Treatment Plant, Victoria.

ecology of intertidal and nearshore areas of the bay adjacent to the WTP: increasing macroalgae, microphytobenthos, phytoplankton and zoobenthos biomass (e.g. Axelrad *et al.* 1979; Brown *et al.* 1980; Dorsey 1982; Wood *et al.* 1991; Magro *et al.* 1995).

Almost certainly as a result of this nutrient enrichment, the WTP attracts large numbers of shorebirds (Charadriiformes), including migratory species that breed in northern Asia and which are subject to international agreements to protect migratory birds and their habitats. The area around the WTP supports internationally important populations (i.e. > 1% of flyway population) of seven shorebirds for part of the year: Double-banded Plover *Charadrius bicinctus*, Curlew Sandpiper *Calidris ferruginea*, Red-kneed Dotterel *Erythrogonys cinctus*, Red-necked Stint *Calidris ruficollis*, Sharp-tailed Sandpiper *Calidris acuminata*, Pied Oystercatcher *Haemotopus longirostris* and Banded Stilt *Cladorhynchus leucocephalus* (Watkins 1993; Dann 2007). The construction of numerous sewage treatment ponds has created a variety of permanent waterbodies that provide habitat for waterfowl and an important drought and hunting refuge for these birds. The plant has an extensive network of waterbodies, covering some 1600 ha and comprising 190 individual ponds (Fig. 2). There is a wide variety of waterbody type, with both constructed ponds (n = 181) and natural wetlands (n = 9). Constructed ponds include 122 operational sewage treatment ponds in eight lagoon systems of inter-connected ponds, and 59 decommissioned sewage treatment ponds now managed as wildlife habitat (Steele 2009). Natural wetlands include four waterbodies that retain something of their natural hydrological regime, with a further five now receiving direct loading of water in a managed regime.

During 1921 parts of the WTP were declared

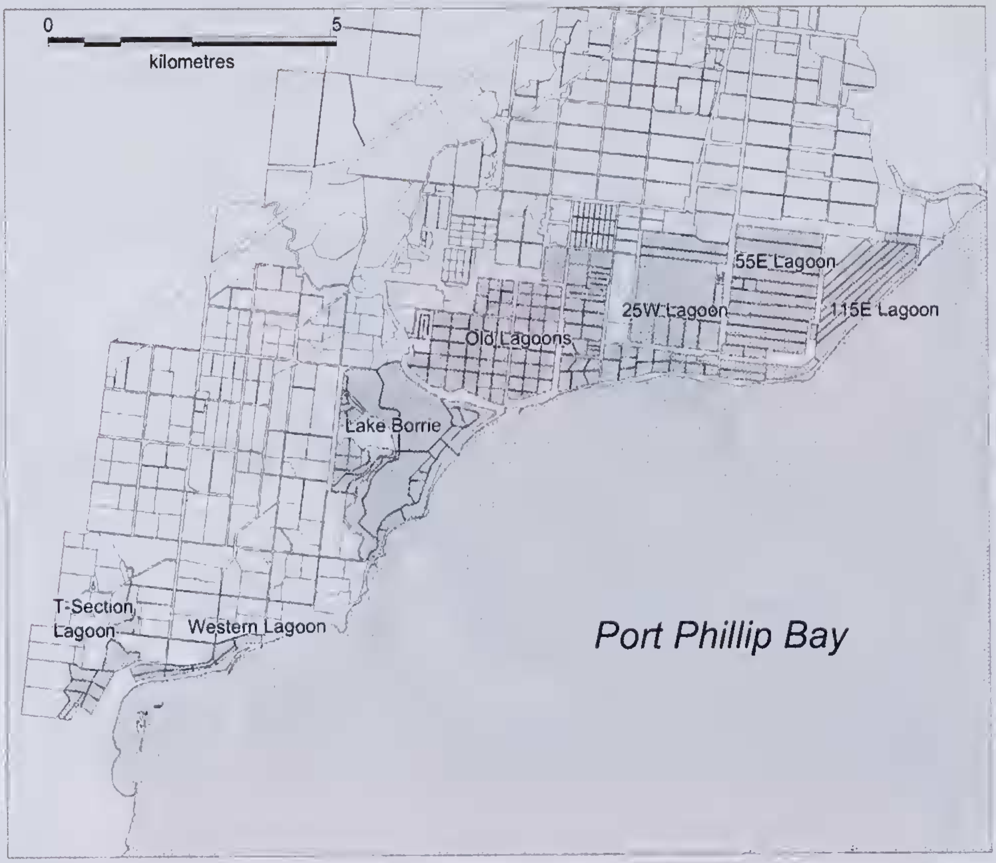

Fig. 2. The Western Treatment Plant, Werribee, with constructed wetlands shown as shaded areas.

a wildlife sanctuary in recognition of the site's avifauna values. Later, in 1982, the entire WTP was included as a component of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site, and formally recognised as a wetland of international importance. The waterbird populations supported at the WTP were the principal value that contributed to the site meeting the criteria for listing as a Ramsar wetland. However, the WTP also supports a significant population of the nationally Vulnerable Growling Grass Frog *Litoria raniformis*; a number of threatened species of plant, including the Spiny Rice-flower *Pimelea spinescens subsp. spinescens*; and two listed vegetation communities: *Natural Temperate Grassland of the Victorian Volcanic Plain* (Critically Endangered, equivalent to Victorian EVC 132 Plains Grassland; and EVC 654 Creekline Tussock Grassland), and *Subtropical and Temperate Coastal Saltmarsh* (Vulnerable, equivalent to EVC 9) (see Brett Lane and Associates 2002; Dann 2007; Ecology Australia 2010). The WTP coastal habitats provide the best known overwintering site in Victoria for the Critically Endangered Orange-bellied Parrot *Neophema chrysogaster* (Orange-bellied Parrot Recovery Team 2006).

As the site manager Melbourne Water is required under the terms of the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 (hereafter referred to as the EPBC Act) to conserve habitat for significant wildlife at the WTP, while still meeting its core commitments to treat wastewater under regulation of the Environment Protection Authority Victoria.

The Environment Improvement Project at the WTP

During the late 1990s Melbourne Water initiated an Environment Improvement Project (EIP) to upgrade its wastewater treatment processes at the WTP as a direct response to the findings of the extensive Port Phillip Bay Environmental Study (Harris *et al.* 1996) and to meet the requirements of the Environment Protection Authority (EPA) Victoria waste discharge licence and the State Environment Protection Policy (Waters of Victoria) in the context of a rapidly growing human population in Melbourne. While the EIP as a whole pre-dated the EPBC Act, one of the final phases of the project, 'Post-effluent Reuse Stage 2', was referred to Environment Australia (now the Commonwealth Department of the Environment) for approval under the Act during June 2002.

The Department approved the Post-effluent Reuse Stage 2 phase of the EIP subject to certain conditions (Environment Australia 2002). Melbourne Water was, among other things, required to implement adaptive management of off-set habitat wetlands to mitigate possible adverse effects on waterbirds or the Growling Grass Frog from treatment upgrades in operational ponds. Our interpretation of the term adaptive management follows the definition: 'a management framework which has built into it the capacity to learn from management decisions and to change management strategies on the basis of improved knowledge' (DNRE 2002: 131). This paper describes how Melbourne Water has endeavoured since 2002 to implement adaptive management to protect the WTP's recognised biodiversity values during necessary sewage treatment upgrades.

Management Approach

Managing multiple wildlife populations at most large Australian sites entails working with large inherent variation and uncertainty. Therefore Melbourne Water seeks continual improvement of its management of biodiversity at the WTP using an adaptive management approach. We understand this to entail:

- precautionary and pro-active provision of 'compensatory' habitat to offset potential future negative effects;
- ongoing investigations to expand our knowledge base and allow sound scientific and data-based management decisions to be made;
- careful monitoring of target population/species' responses to management actions;
- sound management of habitat areas to ensure their value to the target population/species, and;
- frequent review and adjustment of management actions.

Compensatory habitat

Three large sewage treatment lagoons in the west of the WTP, scheduled for decommissioning during the EIP, were set aside to be managed for waterbirds – a key value contributing to the site's listing as a Ramsar Wetland. These lagoons, Lake Borrie, Western and T-Section, comprise 46 ponds and are protected by a *ca* 350 metre buffer zone within which cropping and other intensive land uses are not allowed (see Weston *et al.* 2009). In addition, a further 13 small ponds in the eastern part of the WTP are now managed as habitat ponds. Drains known to be used by Growling Grass Frogs are protected from disturbance or chemical spray drift, and watercourses are provided a 30-metre set-back, fenced to exclude stock. In addition, large-scale habitat improvement works were commenced at the decommissioned Western Lagoon during 2010, including the construction of a new ephemeral wetland intended to provide waterfowl and frog habitat.

Applied research

Since 2002 Melbourne Water has commissioned a large number of research and monitoring projects to improve the understanding of ecosystem structure and functioning at the WTP, and evaluate management actions. Too numerous and varied to detail here, these studies include investigations into waterfowl daily activity budgets (Mustoe and Waugh 2006; Mustoe 2009; Guay 2013), shorebird foraging ecology and movement patterns (Rogers *et al.* 2007, 2013), pond ecosystem structures (Mulder 2005), intertidal mixing zones and infaunal communities (Morris *et al.* 2010; Parry 2013; Parry *et al.* 2013), a trial of multiple effluent outlets (GHD 2013a), disturbance of birds by humans (Glover *et al.* 2011; Guay *et al.* 2013a, 2013b, in prep.; McLeod *et al.* 2013; Weston *et al.* 2012, in press), and satellite tracking of waterfowl (Guay and O'Shea 2012). These studies have not only informed management of the WTP but have contributed to publications that will assist other wetland managers.

One study of particular note, before the decommissioning of Lake Borrie, investigated the likely effects on waterfowl populations at the site of predicted changes in water chemistry following decommissioning. This early model using two years of bird count data and water chemistry sampling predicted that reduced nutrients in the waters of Lake Borrie would have the greatest effect on filter-feeding ducks, perhaps reducing their numbers there by up to 90% (Loyn *et al.* 2002).

Monitoring of significant populations

Commonwealth Department conditions require nine nationally significant wildlife populations at the WTP to be closely monitored to ensure these populations are being sustained and to evaluate management of the site. These populations are: Growling Grass Frog; migratory shorebirds; five waterfowl guilds (dabbling ducks, filter-feeding ducks, diving ducks, grazing waterfowl and grebes); Pied Cormorant *Phalacrocorax varius*; and Straw-necked Ibis *Threskiornis spinicollis*. Results of intensive monitoring of nationally significant wildlife populations are considered in terms of pre-designated 'trigger points' for further investigation or additional management action. These trigger points vary between target populations but typically include ≥10% declines in number over three successive years, or >25% declines over three years. Population declines must be site specific to the WTP to qualify as trigger points for new management at that site. Results are compiled annually, assessed and reported to the Commonwealth Department annually. Loyn *et al.* (2014b) describe the waterfowl monitoring program in more detail.

Management of habitat areas

Management is directed by a number of plans, from the high level WTP Ramsar Site Management Plan (Ecology Australia 2010) to more detailed plans targeting specific values, such as the Growling Grass Frog Management Plan (Renowden 2012) and Terrestrial Margins Management Plan (Wrigley-Dillon 2011). Table 1 lists management interventions undertaken at the WTP since 2002 to improve or maintain habitat. This table does not list ongoing maintenance (e.g. vermin control, weed control, revegetation and water level manipulation in habitat ponds), grassland management (e.g. ecological burn-offs, fencing and controlled grazing), or other actions (e.g. construction/ maintenance of bird-hides, track maintenance, signage, roadside slashing, etc.).

Results of Monitoring

During 2005 two trigger points for increased or changed management intervention were activated: the three-year average number of Growling Grass Frog detected during surveys declined by more than 25%, and the average number of Straw-necked Ibis foraging over former grass filtration paddocks declined by more than 10% in the year after sewage irrigation ceased. Remedial management action was undertaken—with additional ponds set aside to be managed specifically for Growling Grass Frogs and increased paddock irrigation respectively—and monitoring after 2006 showed these populations returned to levels where triggers were not activated.

During 2006 one trigger point was reached when the three-year average number of filter-feeding ducks recorded at the site during 2004–06 was more than 25% lower than the average number recorded during 2001–03. This three-year average trigger for filter-feeding ducks was again reached during both 2007 and 2008. During 2008 a further two guilds of waterfowl reached trigger points when diving duck numbers declined by >10% for three consecutive years and the three-year average number of grebes and diving ducks declined by >25%. During 2009—after 12 years of severe drought and water shortages at the WTP—four trigger points were reached: the three-year average number of Growling Grass Frogs, diving ducks, filter-feeding ducks and grebes all declined by >25%. This was despite the fact that some populations saw increases during late 2009 as the so-called 'Millennium Drought' finally broke across south-eastern Australia.

Table 1. Commitments and implementation of on-ground works associated with habitat wetlands at the Western Treatment Plant.

	Commitment	Implementation
(1)	Experiment to attract filter-feeding ducks (Melbourne Water 2003).	115E Borrow Pit habitat creation works (April 2005).
(2)	Given lack of success of action 1, 85WC-9 earmarked for habitat creation (Melbourne Water 2005).	(a) Allocated as habitat during summer 2005/06 and first drawdown probably spring 2006. (b) Timber added, 2010 and 2011. (c) Major desilt and vegetation clearance (1–16 May 2012).
(3)	Trigger point for Growling Grass Frog reached in 2005. (a) From 2005/06 breeding period 115E Borrow Pit and 5W-9 to be managed for this species (Melbourne Water 2006) (b) 115E Borrow Pit to be drained of stagnant water before re-flooding in September 2010 in an attempt to attract frogs back to these ponds (Melbourne Water 2010).	(a) Done every breeding period from 2005/06. (b) Dewatered in 2007 and again during July 2009, 2010, 2011 and 2012.
(4)	Trigger point for filter-feeding ducks reached in 2006. Undertake habitat improvement works (e.g. positioning of fallen timber) in a large decommissioned sewage treatment pond to mimic conditions in Pond 9 of Lake Borrie—which is the most attractive pond for Pink-eared Ducks at the Western Treatment Plant. This will build upon experience gained during similar habitat creation works at 115E Borrow Pit (Melbourne Water 2007). A further trial of habitat modification, through placing fallen timber in a former sewage treatment pond, is to be conducted during 2007 (Melbourne Water 2007).	Wood added to Lake Borrie Pond 24 (March 2007).
(5)	Experimentally manipulate water flows to Lake Borrie, reducing inflows to extend cumulative retention time in the lake, to determine whether it is possible to promote phytoplankton stocks as food for filter-feeders (Melbourne Water 2007).	See Table 2.
(6)	Trigger point for filter-feeding ducks reached in 2007. Certain decommissioned ponds will be drained, some vegetation allowed to grow, and then flooded to promote nutrient cycling and the production of food for waterfowl (Melbourne Water 2007)	(a) Lake Borrie Ponds 28 and 29 first drawndown from February 2008, flooded again in March 2009; with drawdowns every subsequent spring (sometimes prolonged partial drawdowns due to rainfall and in seeping). (b) Lake Borrie Pond 12 drawdown from February 2013 (after several years of wet delaying response).
(7)	Trigger points for filter-feeding ducks, diving ducks and grebes reached in 2008. Test whether the addition of carbon (in the form of straw or seagrass wrack from the nearby coastline) and/or nutrients (in the form of fertiliser) promotes food resources for waterfowl, particularly filter-feeding ducks, in ponds at Lake Borrie (Melbourne Water 2009).	500 kg straw added to Lake Borrie Pond 22 during September to November 2011 as experiment to assess effect
(8)	Decommissioning of Western Lagoon provides opportunity to re-establish saltmarsh and otherwise improve this area from a habitat perspective. Large-scale habitat improvement works at Western Lagoon (Melbourne Water 2009).	(a) Ponds 4 and 5 drawndown (2008), sludge removed, and bunds removed (March/April 2010) to rehabilitate to saltmarsh. (b) Creation of Q4 Wetland (April 2010).
(9)	Trigger points for filter-feeding ducks, diving ducks and grebes reached in 2009. If required, sludge or biosolids could be added to the Lake Borrie system to ascertain whether this will promote pond productivity sufficiently to attract and support large numbers of waterfowl (Melbourne Water 2009).	This is the subject of advanced planning but is subject to approvals from various regulating authorities. Works are likely to proceed during 2015.

Table 1. Continued.

	Commitment	Implementation
(10)	Trigger point for Growling Grass Frog reached in 2009. T-Section Pond 4 will be managed as an additional Growling Grass Frog pond (Melbourne Water 2010).	Drawdown of T-Section Pond 4 to promote vegetation growth before flooding during Growling Grass Frog breeding period (2011 and 2012).
(11)	Opportunity for creation of new Growling Grass Frog pond arose during desilting works.	Growling Grass Frog pond created at 35E Pond 9 (November 2006).
(12)	Installation of cormorant nesting platforms.	Twenty cormorant nesting poles with 100 platforms installed (August 2004).
(13)	Maintain water levels in T-Section drain over summer (Environment Australia 2002).	Pipe to T-Section drain from T-Section Pond 3 installed (2010).
(14)	Improve water level management at T-Section ponds (VWSG request).	Cross pipes installed between T-Section Pond 1 and Ponds 6 and 7 (October 2006).
(15)	Recommendation of WTP Biodiversity Conservation Advisory Committee.	35E Pond 8 vegetation clearance (April/May 2010).
(16)	Trial multiple outlets for effluent to enrich mudflats (Steele 1996).	Multiple outlets installed 2005/06 (December 2007; GHD 2013a).
(17)	Recommendation of WTP Biodiversity Conservation Advisory Committee.	Drawdown T-Sections Ponds 5 to 7 (done for many years, since at least the 1990s).
(18)	Recommendation of WTP Biodiversity Conservation Advisory Committee.	Weir reset at outlet to Ryans Swamp (February 2005).
(19)	Recommendation of WTP Biodiversity Conservation Advisory Committee.	35E Pond 9 desilt (2008/09).
(20)	Growling Grass Frog management plan (Organ 2003; Renowden 2006, 2009, 2012).	Overwintering harbour (timber and rock) introduced to Growling Grass Frog ponds 5W-9, 5W-10 (2011).
(21)	Request of Clive Minton, to provide shorebird roost (and trapping) site.	Clearing of vegetation from the spit at 5W Pond 9 (April 2005).
(22)	Identified maintenance requirement.	Desilt of outlet to 270S Borrow Pit (January 2006).
(23)	Identified maintenance requirement.	Desilt of outlet to 35E Pond 9 (January 2006).
(24)	Identified maintenance requirement.	Desilt of inlet pipe at Western Lagoon Pond 3 (15 January 2013)
(25)	Staff initiative.	Wood added to Western Lagoon Ponds 1, 2 and 3 (2011).
(26)	Request of the Orange-bellied Parrot Recovery Team.	Supplementary feeding of Orange-bellied Parrots at 55E Lagoon (two winters, one was June 2011).
(27)	Identified maintenance requirement.	Couch Grass removed from upper ponds of Lake Borrie South.
(28)	Recommendation of WTP Biodiversity Conservation Advisory Committee.	35E conservation ponds put onto a two-year drawdown cycle from late 2012.
(29)	Identified need to improve record keeping of water depths in habitat ponds (during drought).	Depth gauges installed.
(30)	Identified need to improve record keeping by community-based birdwatchers.	Pond name boards installed.
(31)	Identified need to improve, community-based monitoring of works sites, beach seaweed deposition, and *Phragmites/Typha* patches.	Fluker posts installed (Nov/Dec 2011).
(32)	2009 Growling Grass Frog trigger point reached.	T-Section Pond 7 and Q4 wetland allocated to Growling Grass Frog habitat.

Altogether four population 'trigger points' were reached during 2012. The rolling three-year average number of (1) diving ducks, (2) filter-feeding ducks, and (3) grebes declined by >25% over the previous three-year period. In addition, (4) the number of Straw-necked Ibis counted foraging across paddocks at the WTP declined by >10% between 2011 and 2012. Thus a number of trigger points have been reached but remedial management has apparently led to a recovery of affected populations, with the exception of filter-feeding ducks and diving ducks and, more recently, Straw-necked Ibis.

Thus post-decommissioning surveys of waterfowl have shown a decline which has been most marked among the filter-feeding ducks, as forecast (Loyn *et al.* 2002). Declines have been most marked at Lake Borrie, which formerly supported the highest numbers of waterfowl of any lagoon at the WTP. The causal factors behind this observed result are unclear. Waterfowl populations will likely have declined as a result of reduced breeding success during the long drought of 1997–2009, and then through dispersal to inland sites to breed following the breaking of the drought (e.g. Loyn *et al.* 2010; Loyn and Swindley 2012; Loyn *et al.* 2014a; Loyn *et al.* 2014b). But the close agreement between modelled response and observation, coupled with an observed reduction in foraging activity at Lake Borrie following its decommissioning (Hamilton *et al.* 2002; Mustoe and Waugh 2006; Mustoe 2009; Guay 2013) suggest that Lake Borrie in 2013 no longer supported very high numbers of filter-feeding ducks.

Management Response at Lake Borrie

In response to these repeated trigger points for filter-feeding and diving ducks at Lake Borrie our adaptive management approach proposes an escalating management intervention (Melbourne Water 2007, 2009) involving the following approaches:

(1) Experimentally manipulating water flows to Lake Borrie, reducing inflows to extend cumulative retention time in the lake, to determine whether it is possible to promote plankton stocks as food for filter-feeders.
(2) Undertaking habitat improvement works (e.g. positioning of fallen timber) in a large decommissioned sewage treatment pond to mimic conditions in Pond 9 of Lake Borrie, which was the most attractive pond for Pink-eared Ducks *Malacorhynchus membranaceus* at the WTP.
(3) Temporarily draining some decommissioned ponds over summer, allowing vegetation to grow—fixing carbon and recycling nutrients from sludge deposits—and then flooding during late winter/spring to promote the production of food for waterfowl the following summer. Given the generally nutrient-rich water and sediments of most ponds at the WTP, this management technique requires careful timing and observation to avoid avian botulism outbreaks.
(4) Supplying nutrients, in some form, to selected decommissioned ponds to promote waterbird food resources in these ponds.
(5) Finally, if required, sludge or biosolids will be added to the Lake Borrie system to promote pond productivity and attract waterfowl. Trucking in concentrated biosolids was considered likely to be inadequate for the purpose and so construction of a new sewage transfer pipeline to replace the decommissioned Main Western Carrier to Lake Borrie will be required.

a. Water inflows manipulation

The first action was carried out from Lake Borrie's decommissioning in December 2004 to winter 2008 (Table 2), with no noticeable success in attracting increased numbers of filter-feeding ducks. Thereafter, from spring 2008, moderate to high inflows were tried, with spring flushes mimicked during some years. While there was no observed increase in filter-feeding ducks at Lake Borrie following this change in management approach, the data are confounded by the severe drought prevailing at that time. Apart from the drought effects on waterfowl populations, environmental water requests could not always be met due to water shortages, blue-green algae contamination of source lagoons, and operational or maintenance constraints.

Simple daily activity budgets have been determined for waterfowl guilds at Lake Borrie Pond since 2000. This provides an indication of how birds are using the pond and was suggested as a possible early warning indicator of changes

Table 2. Planned environmental flows to Lake Borrie post-decommissioning as a sewage treatment lagoon.

Season	Request (ML/wk)	Intent	Comment (where required)
Summer 2004	N/A	Low inflows to allow time for uptake of nutrients from sludge, and development of phytoplankton communities.	25W Lagoon offline and no water supply available.
Autumn 2005	210	Low inflows	25W Lagoon offline and no water supply available.
Winter 2005	210	Low inflows	Drought affected water availability and meant loading to Lake Borrie did not always meet our requested volumes.
Spring 2005	210	Low inflows	"
Summer 2005	210	Low inflows	"
Autumn 2006	210	Low inflows	"
Winter 2006	210	Low inflows	"
Spring 2006	210	Low inflows	"
Summer 2006	175	Low inflows	"
Autumn 2007	210	Low inflows	"
Winter 2007	280	Moderate inflows, given lack of response to low inflow strategy	"
Spring 2007	280	Moderate inflows	"
Summer 2007	200	Low inflows	Extreme drought and water shortages necessitated reduction in planned inflows.
Autumn 2008	230	Moderate inflows	Drought affected water availability and meant loading to Lake Borrie did not always meet our requested volumes.
Winter 2008	280	Moderate inflows	"
Spring 2008	350	Change to high inflows	"
Summer 2008	350	High inflows	"
Autumn 2009	~316	High inflows, with weekly fluctuations	"
Winter 2009	~316	High inflows, with weekly fluctuations	"
Spring 2009	200, with 420 one week	Moderate inflows, with spring flush mimicked	Pulsed loading.
Summer 2009	290	Moderate inflows	
Autumn 2010	267	Moderate inflows	
Winter 2010	250	Moderate inflows	
Spring 2010	280, with 600 one week	Moderate inflows, with spring flush mimicked	Pulsed loading.
Summer 2010	300	High inflows, with weekly fluctuations.	
Autumn 2011	270	Moderate inflows, with weekly fluctuations.	
Winter 2011	280	Moderate inflows.	
Spring 2011	280, with 600 one week	Moderate inflows, with spring flush mimicked	Pulsed loading.
Summer 2011	300	High inflows, with weekly fluctuations	
Autumn 2012	270	Moderate inflows	
Winter 2012	280	Moderate inflows	
Spring 2012	280, with 600 one week	Moderate inflows, with spring flush mimicked	Pulsed loading.
Summer 2012	300	High inflows.	

in habitat quality (Hamilton *et al.* 2002). Subsequent studies found a decline between 2000 and 2006 in the proportion of time birds of some guilds spent foraging, as opposed to time spent resting, moving or preening, at Pond 9 (Hamilton *et al.* 2002; Mustoe and Waugh 2006; Mustoe 2009). However, the most recent observations show some increase between 2007 and 2012 in time spent foraging at Pond 9 by filter-feeding waterfowl (Guay 2013). The only management intervention applied to Lake Borrie Pond 9 since 2007 has been the increase in inflows (Tables 1 and 2). The possibility that pulsed through flow rates might benefit filter-feeding ducks needs to be investigated further.

b. Timber addition
The large Pond 9 of Lake Borrie was established at a natural depression, where many River Red Gum *Eucalyptus camaldulensis* trees became permanently waterlogged. These trees provide valuable habitat complexity and a source of carbon to this pond, which supports many more waterbirds than other ponds in the Lake Borrie system. However, these trees have now been waterlogged for around 80 years and are rapidly becoming lost as habitat, although not as a carbon source. During March 2007 Melbourne Water added felled trees to Pond 24 of Lake Borrie to replicate the carbon source in Pond 9. The volume and distribution of added timber was limited by the reach of excavator arm, but the timber that was added was successful in attracting waterfowl (Melbourne Water 2008). Again, these did not include significant numbers of filter-feeding ducks.

c. Seasonal drawdowns
Two ponds of Lake Borrie, Ponds 28 and 29, were drawn down from February 2008 to March 2009 to allow access to place more timber, as well as to allow vegetation growth to fix carbon and sediment exposure and oxidation (Melbourne Water 2009). It was planned to leave these two ponds shallow or dry over winter and then to flood them in late summer to coincide with the peak demand for wetland habitat for waterfowl after inland waters dry up. However, Black-winged Stilts *Himantopus himantopus* attempted to breed in the lowered ponds. Consequently the ponds could only be flooded in March/April. In subsequent years these two ponds have proved highly attractive to a range of waterbird species during the summer drawdown. However, the ponds have not attracted large numbers of filter-feeding ducks, which are our target, when flooded. This emphasises the difficulty in managing natural systems, and reinforces the need for ongoing, research-based and flexible management.

d. Nutrient addition
'Lake Borrie' comprises 30 ponds in two discrete wetland systems: Lake Borrie North (Ponds 1 to 14, less Pond 10) and Lake Borrie South (Ponds 10 and 15 to 30) (Fig. 3). A simple experimental design was decided, with Lake Borrie North as the 'control' chain of ponds and Lake Borrie South as the treatment chain. Within these two wetland systems Pond 9 supports the greatest diversity of waterfowl of any of the Lake Borrie ponds, whereas the equally large Pond 24 generally supports few waterfowl. To influence Pond 24 we added nutrients to Pond 22, upstream in the chain of ponds. The equivalent pond in the Lake Borrie North chain of ponds is Pond 6 (Fig. 3).

The form of nutrient to be added was strictly limited because of operational and safety considerations. No nutrient addition was permitted to cause effluent discharges to Port Phillip Bay (from Ponds 14 and 30) to exceed Melbourne Water's waste discharge licence issued by EPA Victoria. Nitrogen addition, in the form of commercial fertilizer, was vetoed because of safety concerns in purchasing, transporting and storing this potentially explosive compound. Seagrass wrack was considered but excluded because of concerns that this might increase the salinity of ponds and the possibility that wrack would add excessive potassium to ponds (D Rogers, Arthur Rylah Institute for Environmental Research, pers. comm.).

Eventually a simple experiment adding carbon, in the form of straw, was decided upon. Straw provides a large surface area for microbial slime to adhere to and it was expected that this microbial slime could act as the basis of a food chain and promote zooplankton populations in the treatment and downstream. Over time decomposing straw should add particulate organic carbon (POC) to the water column.

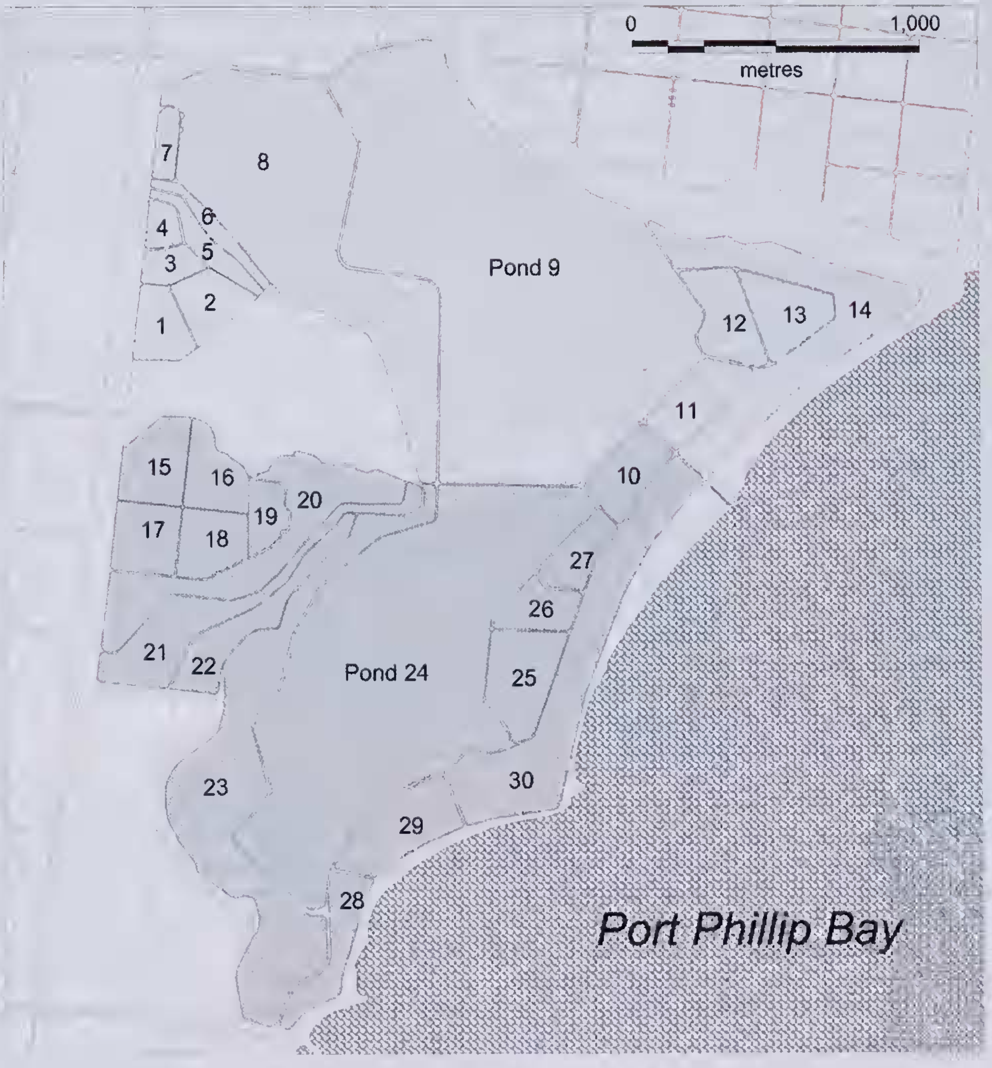

Fig. 3. The Lake Borrie system of 30 ponds in two treatment streams: Lake Borrie North (Ponds 1 to 14, except Pond 10) and Lake Borrie South (Ponds 10 and 15 to 30).

POC is considered to be an important source of food for invertebrates of intertidal mudflats (prey of migratory shorebirds) nourished by effluent discharges from Lake Borrie. There is also the possibility that straw provides cover for zooplankton to hide from predators, promoting zooplankton populations in ponds (e.g. Street 1982; Butler *et al.* 2005). A 500 kg bale of straw (estimated composition *ca* 40% carbon) was sliced into *ca* 10-cm thick 'biscuits'. These were added to Pond 22 over three weeks between September and November 2011.

Water chemistry, zooplankton, phytoplankton and zoobenthos (macroinvertebrate) sampling was initiated in the four Lake Borrie ponds from November 2009, following a scoping study (Bryant and Papas 2008). This sampling takes place four times per year and is planned to provide ongoing data on potential prey for waterfowl in these ponds before, during and after nutrient addition (GHD 2013b).

Benthic macroinvertebrates

Airlift sampling was utilised to sample macroinvertebrates in the pond sediments. The apparatus consisted of a 12 litre SCUBA tank attached to a base unit that was in turn attached to a 250 μm mesh bag and collecting vessel. The base net was placed firmly on the pond bottom and when the pressurised air tank was opened the benthic macroinvertebrates, without excess sediment, were collected. At each sampling point three sub-samples were taken, with each consisting of a 6 second burst. Sub-samples were combined and treated as one sample. These samples were preserved in 70% ethanol and retained for identification in the ALS Aquatic Ecology laboratory (now GHD Aquatic Ecology laboratory). All macroinvertebrate samples were processed using stereo or compound microscopy, with organisms identified to species (where possible) using published keys listed in Hawking (2000). All macroinvertebrates were picked and enumerated with the exception of samples with superabundant Oligochaeta (worms) where approximately 10% of all worms were identified and total worm abundance was estimated based on this sub-sample.

Zooplankton

Zooplankton was collected using a modified 11 L perspex Schindler-Patalas trap. At each sampling point five sub-samples were collected from at least 10 cm below the water surface. Sub-samples were consolidated into one sample, filtered through a 60 μm mesh net and preserved in 70% ethanol. Samples were then dispatched to the Australian Waterlife laboratory for processing and identification. Samples were processed using stereo or compound microscopy, with organisms identified (where possible) to species level. Zooplankton and rotifer abundances are reported as the total number of organisms per litre.

Phytoplankton

Whole water samples per sampling point consisted of a single sub-surface 1 L water sample. These samples were stored at approximately 4°C, protected from light, until they were transferred to the ALS Botany laboratory. Samples were then preserved using an appropriate volume of Lugol's Solution and identified to species level where possible, using the Sedgwick-Rafter method, under compound microscopy. Phytoplankton abundances are reported as cells/units per millilitre.

Results for all three taxonomic groups were summarised by abundance and richness (number of taxa recorded) for two periods: before (four sampling runs per year, November 2009 to July 2011, or 8 replicates) and after the addition of straw (8 replicates). The resulting 2009-11 and 2012-13 means were compared using a two-tailed t-test, assuming unequal variances.

Results of the Lake Borrie Nutrient Addition

The results of zooplankton, zoobenthos and phytoplankton sampling are summarised in Tables 3–5 and Figs 4–6. Within the limits imposed by our simplistic experimental design there is no evidence that the addition of straw was associated with any increase in waterfowl food resources in treatment ponds. All ponds showed increases in zoobenthos (macroinvertebrates) abundance in the periods 2009–11 and 2012–13 and this increase was not larger in the treatment ponds 22 and 24 (Fig. 4a, Table 3a). Interestingly, the pond that had straw added, Pond 22, displayed significant declines in macroinvertebrate taxonomic richness ($t = 3.46$, $P < 0.01$) in contrast to the other three ponds (Fig. 4b, Table 3b). All four ponds showed significant declines in abundance of zooplankton (including rotifers) between the two periods (Fig. 6a, Table 5a). Patterns of change in zooplankton taxonomic richness were similar in both the treatment and control ponds. Zooplankton richness decreased in higher ponds while increasing in both downstream ponds (Fig. 6b, Table 5b). There was an apparent increase in phytoplankton abundance in Pond 22 ($t = 2.44$, $P < 0.05$), where the straw was added, in contrast to the other three ponds (Fig. 5a, Table 4a).

Discussion

The value of long-term monitoring at multiple sites

As we obtain further monitoring data it is apparent that significant wildlife populations at the WTP vary widely between years, making interpretation and evaluation of management

Table 3a. Abundance of zoobenthos (macroinvertebrates) per sample from four ponds before and after addition of straw to Pond 22.

Pond	2009-11	2012-13	*t*-test
LB Pond 6 Control	Mean = 102.61 SE = 23.20 *N* = 28	Mean = 255.54 SE = 30.82 *N* = 28	$t = 3.9647$ $P < 0.01$
LB Pond 9 Control - downstream	Mean = 110.00 SE = 16.75 *N* = 44	Mean = 142.54 SE = 22.33 *N* = 26	$t = 1.1657$ n.s.
LB Pond 22 Treatment	Mean = 197.69 SE = 34.84 *N* = 32	Mean = 230.10 SE = 28.69 N = 28	$t = 0.7175$ n.s.
LB Pond 24 Treatment - downstream	Mean = 123.52 SE = 21.25 *N* = 44	Mean = 198.64 SE = 52.20 *N* = 28	$t = 1.3327$ n.s.

Table 3b. Diversity (taxa recorded) of zoobenthos (macroinvertebrates) from four ponds before and after addition of straw to Pond 22.

Pond	2009-11	2012-13	*t*-test
LB Pond 6 Control	Mean = 9.75 SE = 0.75 *N* = 28	Mean = 9.96 SE = 0.41 *N* = 28	$t = 0.2503$ n.s.
LB Pond 9 Control - downstream	Mean = 8.57 SE = 0.48 *N* = 44	Mean = 9.96 SE = 0.58 *N* = 26	$t = 1.8424$ n.s.
LB Pond 22 Treatment	Mean = 14.09 SE = 0.76 *N* = 32	Mean = 10.86 SE = 0.54 *N* = 28	$t = 3.4628$ $P < 0.01$
LB Pond 24 Treatment - downstream	Mean = 9.07 SE = 0.44 *N* = 44	Mean = 10.00 SE = 0.76 *N* = 28	$t = 1.0666$ n.s.

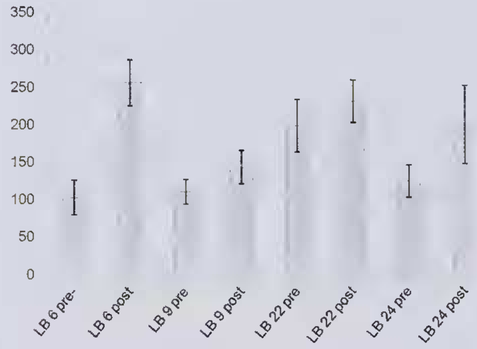

Fig. 4a. Zoobenthos (macroinvertebrate) abundances, per sample, in four ponds, 2009-11 and 2012-13. Standard error bars are shown.

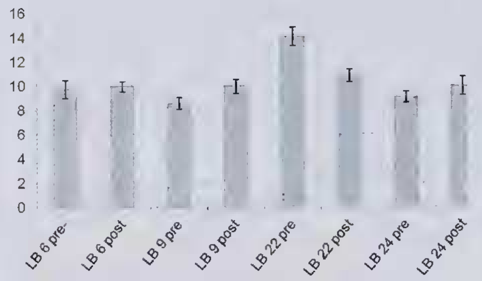

Fig. 4b. Zoobenthos (macroinvertebrate) diversity in four ponds, 2009-11 and 2012-13. Standard error bars are shown.

efforts problematic. It is difficult to assess to what degree downward trends in population are site-specific, and due to treatment process changes at the WTP, or more widespread and resulting from regional effects, such as long-term drought. Results from long-term surveys of wetlands across south-eastern Australia show that numbers and breeding of waterbirds declined significantly during the drought (Kingsford *et al.* 2005; DEC 2006; Chambers and Loyn 2006; Kingsford and Porter 2007; Norman and Chambers 2010). Thus, observed declines in waterbird populations at the WTP in recent years were likely to be heavily influenced by regional, mostly ex-situ, population trends and reduced breeding success (Loyn *et al.* 2014a). Indeed, an assessment of waterfowl numbers in Victoria shows that the WTP supported a significantly greater proportion of the State's waterfowl during the 1997–2009 drought than in previous years, with around 70% of the waterfowl counted during the Summer Waterfowl Count recorded at this one site.

Total numbers of waterfowl counted during the Victorian Summer Waterfowl Count increased dramatically in 2012 (almost six-fold) over the very low count for 2011. However, the EPBC 2002/688 trigger point (>25% decline in a three year period) was still exceeded for diving ducks, filter-feeding ducks and grebes for the three-year period 2009/10 to 2011/12. In each case this was due to the impact of the extremely low counts of 2010/11 on the three year mean. Numbers and distributions of Australian waterbirds at coastal sites are linked to patterns of rainfall and filling of ephemeral inland wetlands in our large, dry continent with its variable rainfall. The first decade of the 21st century saw a major drought affect much of southern Australia, and this inevitably affected the number of waterbirds using the WTP as national populations declined. However, the site also played a major role in providing a drought refuge for native waterbirds over this period. Sudden declines in waterbird numbers at the WTP during 2008 and 2010 were clearly related to rains and flooding in inland northern Australia. The count increases of 2012 are likely to reflect a return of individuals that had moved north to breed, plus immature birds recruited during those breeding events.

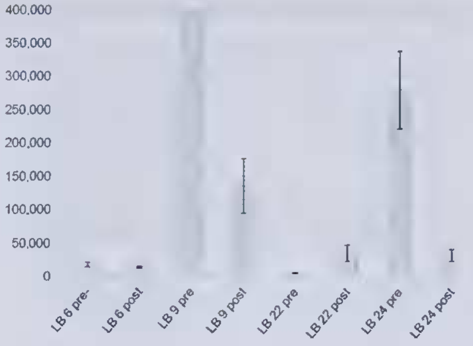

Fig. 5a. Phytoplankton abundances, per sample, in four ponds, 2009-11 and 2012-13. Standard error bars are shown.

Fig. 5b. Phytoplankton diversity in four ponds, 2009-11 and 2012-13. Standard error bars are shown.

Thus it would seem that the WTP is becoming more important as a waterfowl refuge in recent years, not less so, and that population trigger points for extra management effort may be set unnecessarily low. Nonetheless, extensive works are being planned to return additional nutrients to Lake Borrie to meet Melbourne Water's commitments to respond to observed declines in waterfowl numbers following the EIP.

Pilot nutrient addition study

The lack of any result through the experimental addition of straw is disappointing. Straw was not the preferred additive but safety and other considerations meant the experiment was limited to this form and quantity of carbon. Further, the pond layout precluded multiple 'experimental' (nutrients added) and 'control'

Table 4a. Phytoplankton abundance per sample from four ponds before and after addition of straw to Pond 22.

Pond	2009-11	2012-13	*t*-test
LB Pond 6 Control	Mean = 17 172.86 SE = 3 411.26 *N* = 28	Mean = 13 383.54 SE = 1 267.21 *N* = 28	*t* = 1.0413 n.s.
LB Pond 9 Control - downstream	Mean = 1 074,052.57 SE = 368 026.45 *N* = 44	Mean = 135 814.79 SE = 40 706.98 *N* = 28	*t* = 2.5339 P < 0.05
LB Pond 22 Treatment	Mean = 5 107.47 SE =417.82 *N* = 32	Mean = 34 996.79 SE = 12,252.54 *N* = 28	*t* = 2.4380 P < 0.05
LB Pond 24 Treatment - downstream	Mean = 279 384.23 SE = 58 050.59 *N* = 44	Mean = 31 459.46 SE = 8783.84 *N* = 28	*t* = 4.2228 P < 0.01

Table 4b. Diversity (taxa recorded) of phytoplankton from four ponds before and after addition of straw to Pond 22.

Pond	2009-11	2012-13	*t*-test
LB Pond 6 Control	Mean = 19.18 SE = 0.90 *N* = 28	Mean = 18.75 SE = 0.78 *N* = 28	*t* = 0.3593 n.s.
LB Pond 9 Control - downstream	Mean = 23.95 SE = 0.89 *N* = 44	Mean = 28.32 SE = 1.40 *N* = 28	*t* = 2.6364 P < 0.05
LB Pond 22 Treatment	Mean = 17.53 SE = 0.63 *N* = 32	Mean = 22.11 SE = 0.96 *N* = 28	*t* = 3.9797 P < 0.01
LB Pond 24 Treatment - downstream	Mean = 26.5 SE = 0.65 *N* = 44	Mean = 21.5 SE = 0.67 *N* = 28	*t* = 2.2762 P < 0.05

ponds. Monitoring of pond biota in the experimental ponds will continue to ascertain if long-term effects become evident. This monitoring will be of value when Lake Borrie is re-engaged with the treatment process and receives partially treated sewage in the near future.

Conclusion

This paper described adaptive management from the perspective of the land manager of a large property. While targeted adaptive management occurs for a small number of individual species (e.g. Dowling and Weston 1999; Maguire *et al.* 2011), adaptive management of sites is more complex because of multiple and sometimes conflicting values and responses. Lessons from 12 years of attempting adaptive management of multiple biodiversity values at the WTP include the importance of long-term standardised monitoring of values, despite its cost. Population levels of target species can fluctuate widely between seasons, years, and longer term periods following climatic 'cycles'. To evaluate management effectiveness one needs long-term monitoring data, ideally including sites external to the managed property, to ascertain site-specific population responses.

Acknowledgements

A critically important element of Melbourne Water's adaptive management approach to biodiversity conservation at the site is the WTP Biodiversity Conservation Advisory Committee. This Committee was first formed in 1986, when it was called the WTP Wildlife Advisory Committee, and provides specialist advice to Melbourne Water on the conservation and management of the WTP's unique native biodiversity values. The Committee consists of representatives from

Table 5a. Zooplankton abundance (including rotifers) per sample from ponds before and after addition of straw to Pond 22.

Pond	2009-11	2012-13	*t*-test
LB Pond 6 Control	Mean = 3 550.25 SE = 1 286.11 *N* = 28	Mean = 189.28 SE = 56.26 *N* = 28	*t* = 2.6108 P < 0.05
LB Pond 9 Control - downstream	Mean = 23,448.72 SE = 5 690.78 *N* = 44	Mean = 387.62 SE = 53.04 *N* = 26	*t* = 4.0522 P < 0.01
LB Pond 22 Treatment	Mean = 6 151.03 SE = 1 489.47 *N* = 32	Mean = 140.11 SE = 23.24 *N* = 28	*t* = 4.0351 P < 0.01
LB Pond 24 Treatment - downstream	Mean = 19,900.95 SE = 4 488.65 *N* = 44	Mean = 509.15 SE = 95.82 *N* = 28	*t* = 4.3092 P < 0.01

Table 5b. Diversity (taxa recorded) of zooplankton (including rotifers) from four ponds before and after addition of straw to Pond 22.

Pond	2009-11	2012-13	*t*-test
LB Pond 6 Control	Mean = 12.11 SE = 0.67 *N* = 28	Mean = 9.43 SE = 0.51 *N* = 28	*t* = 3.1825 P < 0.01
LB Pond 9 Control - downstream	Mean = 8.20 SE = 0.43 *N* = 44	Mean = 10.29 SE = 0.49 *N* = 26	*t* = 3.2007 P < 0.01
LB Pond 22 Treatment	Mean = 11.25 SE = 0.52 *N* = 32	Mean = 9.57 SE = 0.56 *N* = 28	*t* = 2.1914 P < 0.01
LB Pond 24 Treatment - downstream	Mean = 7.61 SE = 0.37 *N* = 44	Mean = 9.36 SE = 0.58 *N* = 28	*t* = 2.5347 P < 0.05

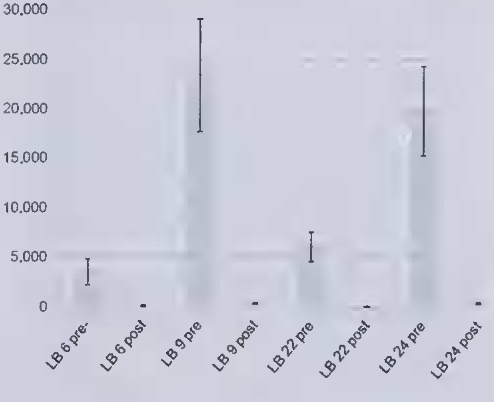

Fig. 6a. Zooplankton abundances, per sample, in four ponds, 2009-11 and 2012-13. Standard error bars are shown.

Fig. 6b. Zooplankton diversity in four ponds, 2009-11 and 2012-13. Standard error bars are shown.

relevant Government agencies, a number of environmental non-governmental organisations, and experts in a number of biological fields. The experience and knowledge of this Committee is of enormous value to Melbourne Water, which relies on its expert advice to guide biodiversity conservation, land management and operations at the WTP.

Numerous State government agencies, universities, consultancies and NGOs have been involved in research, monitoring and/or management planning at the WTP since 2002. Too numerous to mention 'we wish to express our gratitude to these bodies and individuals for the volume and quality of data now available to inform and evaluate management at the WTP.

We wish to thank specifically Dr Mike Weston (Deakin University) and a reviewer for their most helpful comments on drafts of this paper, and Ben James (Melbourne Water's former Werribee Agriculture Group) for his assistance with the practical implementation of the nutrient addition study.

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One Hundred and Three Years Ago

Report

A report of the excursion to the Metropolitan Farm at Werribee on Saturday, 21st October, was given by the leader, Mr. G. A Keartland, who said that there had been a good attendance of members, who, besides studying the natural history of the farm, had the opportunity of seeing how the sewage of Melbourne was disposed of. The bird-life, though numerous, was not very varied, and he had been somewhat disappointed in the results of the afternoon. It was interesting to find the little Grass-bird, Megalurus gramineus, nesting quite close to the shore-line. Regarding the botanical aspects of the excursion, Dr. Sutton reported that the flora was very similar to that on the eastern side of Port Phillip. The principal plants noted were:— *Atriplex cinereum* (tree form), *Salicornia arbuscula, S. Australis, Suceda maritima, Apium prostratum, Mesembryanthemum australe, Frankenia lavis, Samolus repens, Wilsonia rotundifolia, W. humilis,* and *Cotula filifolia*.

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